Ongoing meteor work

Concerning the height of meteors

Lorenzo Barbieri[1,2], *Gaetano Brando*[1]

The height at which the meteors appear in the sky is not constant. The analysis of observational data shows a wide random variability. Within this we can see a systematic variation, both during the year and during each day. It has a sinusoidal shape, with an amplitude of 8 km around a mean value of 99 km. This systematic variation seems to depend on the 'i' parameter, 'i' being the inclination of the meteors orbital plane with respect to the ecliptic plane.

Received 2019 May 21

1 Introduction

The present study starts with the observational data collected in a year of RAMBo activity (Radar Astrofilo Meteorico Bolognese).

2 What is RAMBo

RAMBo is a meteor bistatic radar set-up placed at the AAB (Associazione Astrofili Bolognesi) headquarters. It works according to the "meteor scatter" principle.

Its purpose is to capture the meteor radio echoes and to record their characteristics. The set-up has been active since 2013, and is recording almost one million meteors per year.

As soon as a small meteoric particle entering the Earth's ionosphere impacts the air molecules, it disintegrates, generating a cascade of ionized molecules.

A long and narrow cylinder consisting of ions and free electrons is then created, which persists for a short period of time before the ambipolar diffusion and the recombination process dissolves it. The free electrons, when hit by a radio signal, oscillate at the frequency of this signal, behaving in turn as an emitter of an electromagnetic field. From the radioelectric point of view, the cylinder of free electrons therefore behaves like a reflective object, analogous to an airplane, a satellite or any other flying object. The re-emission of the incident radio signal is called "meteor scatter" (Figure 1).

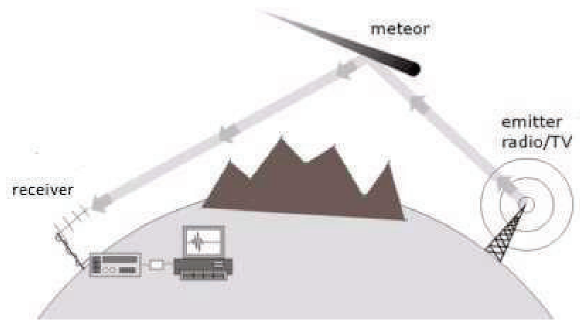

Figure 1 – Meteor scatter.

If we have a radio transmitter that illuminates a portion of sky and a distant receiver tuned to the same frequency, we can record the received radio echoes and evaluate the signals characteristics.

RAMBo uses the signal emitted by the military radar transmitter GRAVES located near Dijon (France), that continuously transmits in VHF at very high power (the frequency is approximately 143 MHz) – Figure 2.

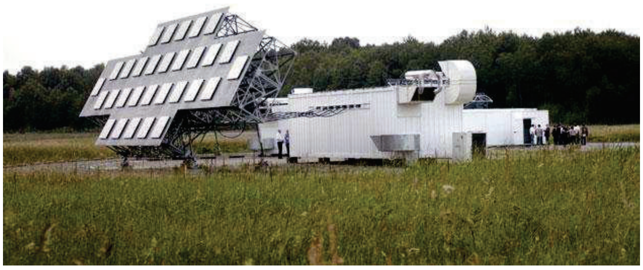

Figure 2 – The GRAVES transmitter.

Its transmission is turned upwards and therefore, both for this reason and for the shielding opposite from the Alps, it cannot be received directly from Bologna. Our receiver has a 10 elements Yagi antenna pointing in azimuth in the direction of the transmitter, and in radiation angle at about 25 degrees over the horizon, where we have calculated to be the reflection point with the upper layers of the atmosphere (Figure 3).

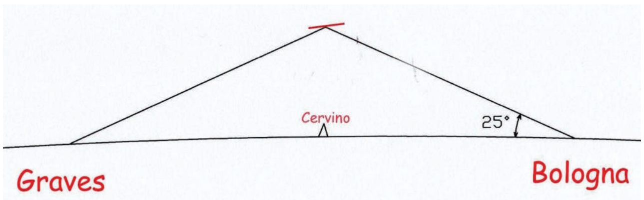

Figure 3 – The radio signal path in a forward meteor scatter.

The audio signal produced by the receiving device is analyzed in frequency and digitized using a microprocessor. Using this technique, each meteor echo is catalogued in a text file in which, together with other data (progressive event number, event number in the hour, date and time (UT), echo duration in milliseconds) the signal amplitude is recorded.

[1]RAMBO meteor group, AAB, Associazione Astrofili Bolognesi, Bologna, Italy.
[2]Email: barbieriofiuco@gmail.com

IMO bibcode WGN-474-barbieri-height
NASA-ADS bibcode 2019JIMO...47..108B

For further explanation see RAMBO web page[a], and to see our data, visit the dedicated page of the Associazione Astrofili Bolognesi website[b].

3 The radio signal amplitude

When analyzed over the year, the average value of the signal amplitude is not constant, but instead presents a systematic variation having a sinusoidal course.

This variation over the time is even more pronounced if we analyze the daily data: in this we note that in the morning the radio amplitude is greater, and it then gradually diminishes during the day, and then increases again overnight (Figure 4).

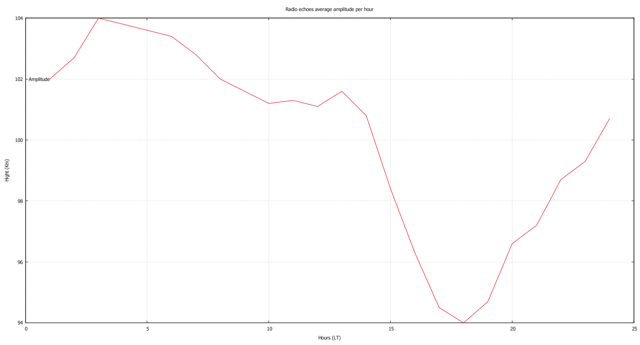

Figure 4 – Radio signal amplitude during a day.

A first evaluation, based on the length of the path covered by the radio signal from the transmitter to the receiver, led us to think about the height of the meteors, and on the possibility that a change in height might influence the length of the path and consequently the attenuation of the received signal power.

Hence, we decided to verify this hypothesis by looking at the trend in the meteor heights via a different observational method, i.e. video observations.

4 Video observation of meteors

The observation of meteors through the use of video cameras is a technique that has been performed for some years now by both amateur and professional astronomers.

It is based on the use of video cameras of good sensitivity, both analogue and digital, equipped lenses that are of very short focal length and as bright as possible. The images provided by these cameras are then digitized and processed by software.

In the professional field a variety of software packages have been developed via a number of different projects.

In the field of amateur astronomy, the first software developed was Metrec, and this was designed to run on MS-DOS platforms. Then, after the advent of Windows, UFO was developed, a Japanese software package composed of three parts: one for live image control and video clips recording of luminous transients, the second one to analyze these clips and to calculate the data related to meteor traces, and the third one to triangulate the observations obtained from a same meteor by two or more observers.

The practice of the automatic observation of meteors with video cameras, coupled with the relatively low costs involved, led to a rapid increase in observers. The data produced by these observations came together in a number of large databases among which we can mention Edmond, dedicated to the European area, SonotaCo, concerning Japan, and Bramon, a recent addition that stores observations made in Brazil. The data examined in this article come essentially from Edmond, both because it is a database in which we also participate, and because it is larger than SonotaCo. The Japanese database is far more "clean" than the European one, the latter including several gaps and stray values, thus making it necessary for us to perform an additional job of "cleaning up" the data. Bramon is still quite small and some gaps, especially in the temporal sphere, led us to disregard it. Hence, the analyses we carried out were essentially from the European samples, but after a verification we can assert that the trends and the measured quantities are completely in line with those obtainable from the Japanese data.

The sample of data we used was mainly "Edmond2016" referring to the last year available at the time when we started to write this article. As for the SonotaCo data, with Edmond we also performed checks on previous years, so as to always obtain homogeneous values and trends. Edmond2016 is a database that contains data relating to approximately 70 000 meteors, observed by observers spread all over the Europe. The software tools we used for data analysis were mainly Python and Gnuplot.

5 Meteor heights

For the analysis of the height of the meteors, we initially used the datum "H1" representing the height from the ground of the point where the visual trace of the meteor begins.

Looking at the annual trend, we see that a random variation overlaps a systematic variation with a sinusoidal trend. The maximum average height is reached at the autumn equinox and the minimum at the spring equinox (Figure 5).

The subtraction of the contribution of the main swarms (Quadrantids, Lyrids, Eta Aquariids, Perseids, κ Cygnids, Aurigids, Southern Taurids, Orionids, Northern Taurids, Leonids, Geminids and Ursids) shows how the sinusoidal trend is typically primarily of the so-called sporadic meteors (Figure 6).

For this subtraction we have eliminated all the meteors that UFO determined as coming from the corresponding radiants.

Even in the analysis of the daily data, which is limited to the hours in which the meteors are observable, we can still see signs of a sinusoidal trend, in which the meteors start higher in the morning and lower in the evening (Figure 7).

[a] `http://www.ramboms.com/index_eng.html`
[b] `http://www.associazioneastrofilibolognesi.it/rambo/`

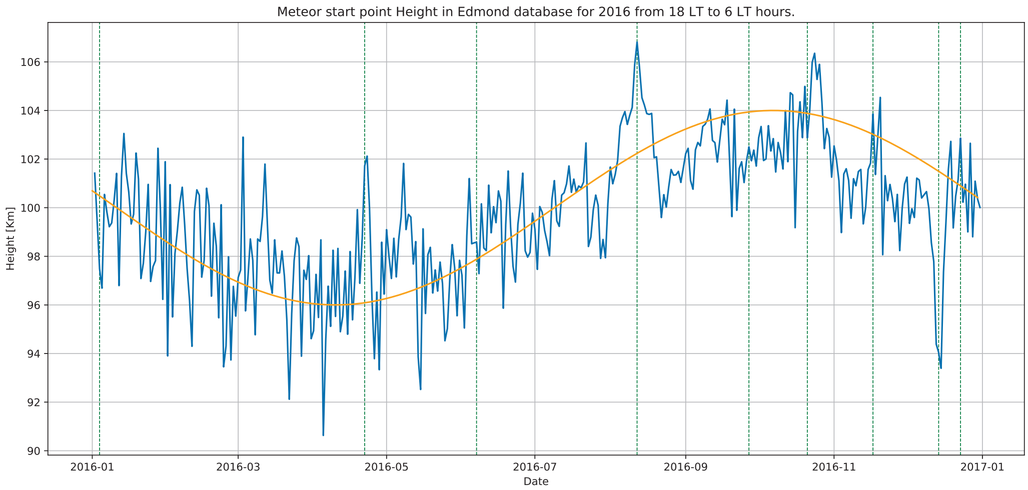

Figure 5 – Average meteor heights during the year. (The yellow line is a generic sinusoidal curve.)

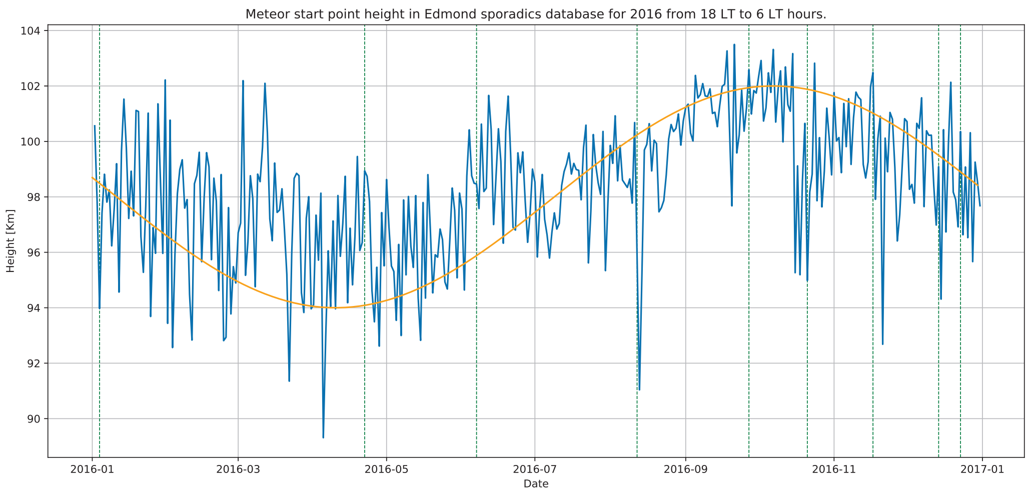

Figure 6 – Average meteor heights: sporadics and minor showers only. (The yellow line is a generic sinusoidal curve.)

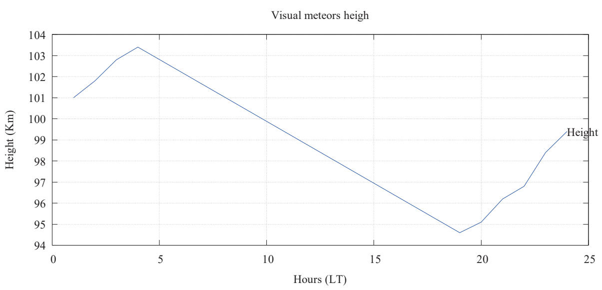

Figure 7 – Average meteors height during the night.

The average spread in the meteor start heights is about 8 km around an average start height of about 99 km.

It is, however, not only the starting height that changes: the up and down movement covers all of the meteoric trace. In fact the analysis of the H2 data that represents the height above the ground where the meteors "go out" undergoes the same identical variation.

This is illustrated by Figure 8, in which it can be seen that the average lengths of meteors is constant.

6 Why do meteor heights vary?

What is the reason why meteors either appear higher or lower, depending on the season of the year or the time of day?

The atmosphere temperature?

The speed of the meteoroids?

The radiant position?

The first two explanations can be cleared ruled out by comparing the average start heights for two of the major winter showers, Geminids and Ursids.

As can be seen in Figure 9, the average height of the Geminids is 93.5 km while Ursids height is 103 km. The two showers peak only 8 days apart, which cancels the hypothesis concerning significant variations of the ionosphere temperature or other atmospheric physical parameters. Moreover Geminids and Ursids are streams with roughly the same speed in the reference system of the solar system: 32 km/s for the former and 33 km/s for the latter. This consideration therefore leads us to also reject the second hypothesis, regarding the streams' own velocities.

There is, however, a relevant factor that helps us to reflect on the cause of the phenomenon. As we can see, the height of the meteors has a daily maximum at six

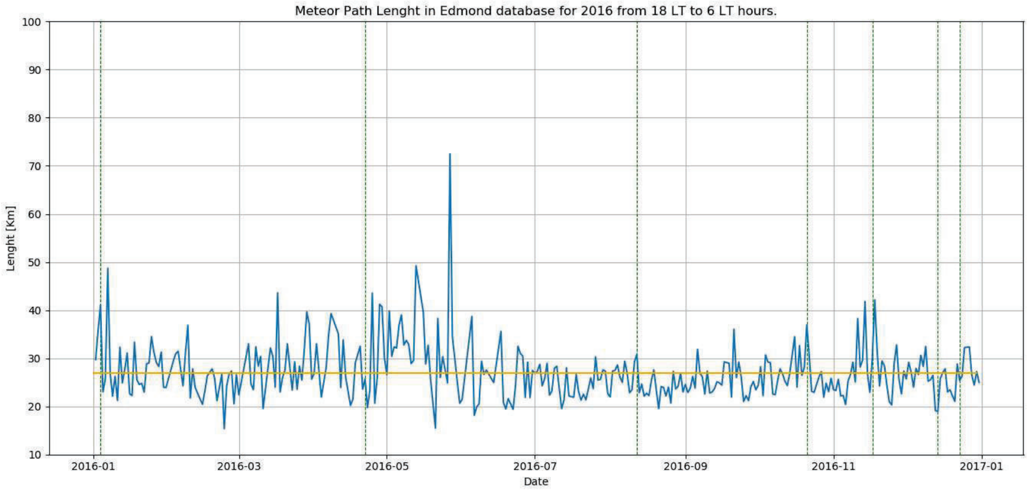

Figure 8 – Average meteors length.

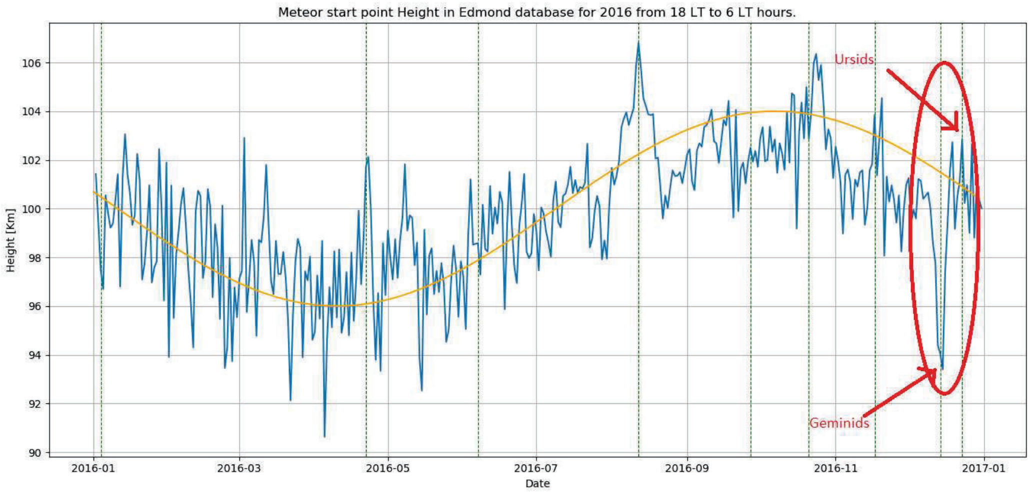

Figure 9 – Comparison between Geminids and Ursids.

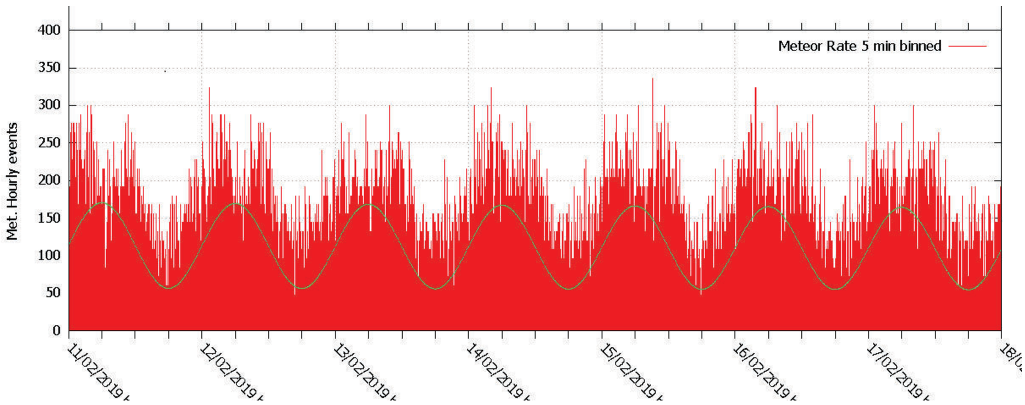

Figure 10 – Hourly rate measured by RAMBo (5 minutes bin).

in the morning (local time), and a minimum at 18^h. It is just as for the better known parameter: the hourly rate.

The hourly rate also sees meteor numbers far more abundant at six in the morning than at 18^h.

In Figure 10 we can see the hourly rate measured by RAMBo in a generic week. In it the trend is almost pure sinusoidal, less than a daily decrease of pings at 6 LT between two peaks, before and after. This phenomenon is due to the "observability function" of the bistatic set-up that depends on the radiation lobes of the GRAVES radar, the reception lobe of the RAMBo antenna and the geometry of the meteor trajectories (Verbeeck, 1997).

The reason for the sinusoidal behavior of the meteoric rhythm resides, as it is known, in the position of the observer with respect to the apex (or to the anti-apex). Thinking about meteoric impacts, if we consider the motion of the Earth around the Sun we can define the apex as the point towards which the Earth seems to be directed in its movement, while the anti-apex is the opposite direction.

7 Geometry of meteoric impacts

If we consider the motion "of the spaceship Earth" around the sun we define apex as the point towards which the Earth seems to be directed in its movement, while the anti-apex is the opposite point (Figure 11).

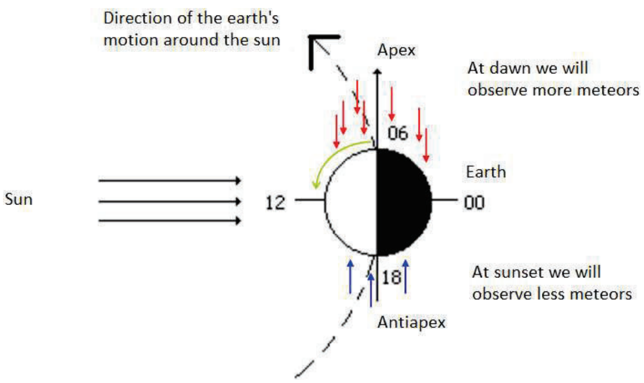

Figure 11 – Comparison of meteor rates around sunset and towards dawn.

The apex is therefore the point that we see in front of us looking ahead, while the anti-apex is what we see from the rear window. From this last observation point all the meteors that can hit the Earth are exclusively those which are faster then us. They are a fraction of the totality (in blue in the drawing). In contrast, in the forwards direction we can be hit by all the meteors, both slow or fast. And this is because the speed of the impact (in vectorial form) is:

$$V_i = V_m - V_t$$

where V_i is the speed of the impact, V_t the speed of the Earth, while V_m is the meteor speed, which depends both on the speed of the meteor in the solar system and on the angle of inclination of its own orbit with respect to the terrestrial one. This is therefore the reason why at dawn (on average at 6am locally) the Earth is hit by the greatest possible number of meteors, while at around 6pm, we record the minimum.

As we have seen, even the phenomenon we are investigating i.e. the height of the meteors, shows a maximum when the observer is near the apex, and a minimum when it is near the anti-apex. We can deduce that the cause of the variation lies in the angle between the point of origin of the meteors and the apex. This consideration calls into question the orbital parameters of meteors, first of all the parameter "i" defined as "the inclination of the orbital plane with respect to the ecliptic plane" (Jenniskens, 2006).

Figure 12 shows the "i" parameter as calculated by UFO for each meteor.

It should be noted that the trend of the "i" parameter is completely similar to that of the graph (Foschini, 1999).

Therefore, trying to put the two quantities "H1" and "i" directly in relation, we obtain a proportional relation.

In the Figure 13, each dot represents the height and inclination of a meteor for each of the meteors recorded for 2016.

Therefore, the closer "i" that approaches to 180°, the more that the angle from the apex becomes closer to 0 and vice versa for those tending to 0.

As proof of this we can put the inclination i directly in relation to the impact speed: in Figure 14, the relation is evident.

Hence, we can see that the direction of origin of the meteor affects the speed of impact.

In Figure 15, the measured speed and height of the meteors show a direct proportionality.

The small deviation from the line at the bottom left could be attributed to the debris, the return from space of anthropogenic space debris. Such bodies, as is known, have lower speeds than those of slower meteors.

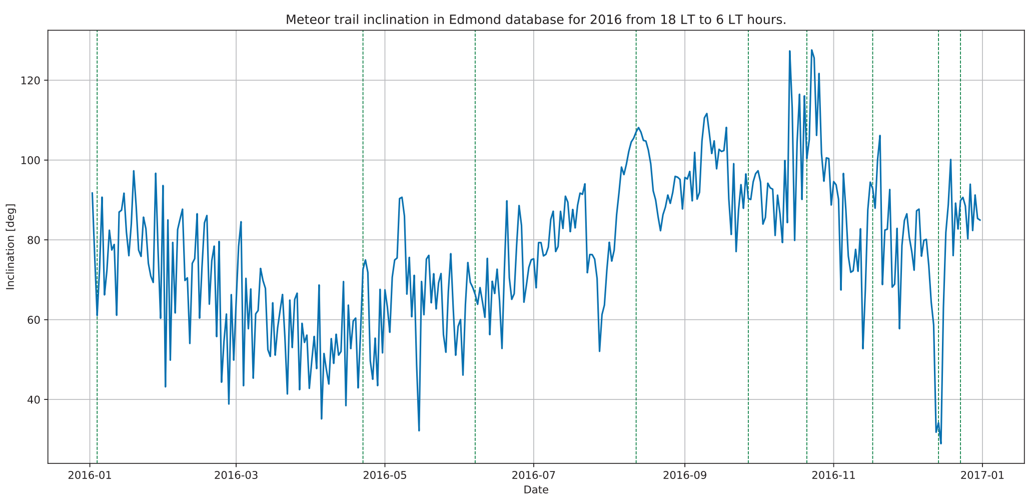

Figure 12 – Average of i parameter, in the year.

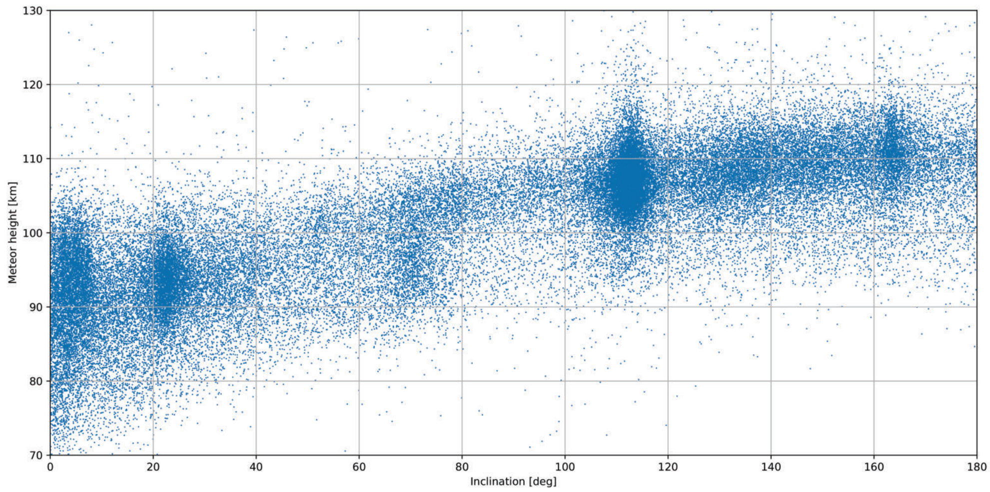

Figure 13 – Inclination vs height.

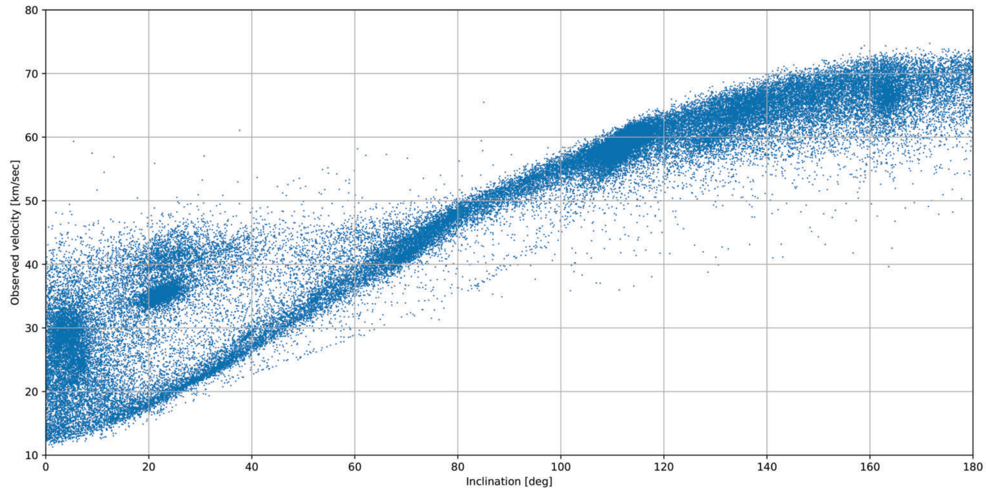

Figure 14 – Speed vs inclination.

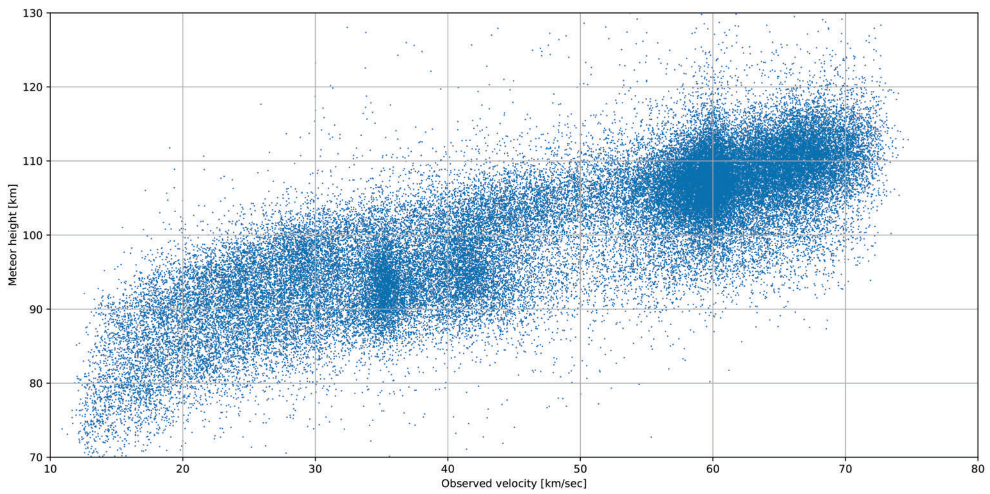

Figure 15 – Height vs speed.

8 Meteor inclination and heights as a function of time

Figures 12 and 14 show how for the great majority of meteors both the height at which they light up, and the speed of entry are linked to the parameter "i" defined as "the inclination of the orbital plane with respect to the plane of the ecliptic" (Jenniskens, 2006).

This parameter varies between 0° and 180° due to the rotation of the Earth. To this consideration, we subtract the Geminids and Taurids (both the STA and the NTA) that show a different behavior (Figure 16), probably due to the particular orbit of the parent body.

The direction of origin of the meteor with respect to the apex does not change only because of the orbital

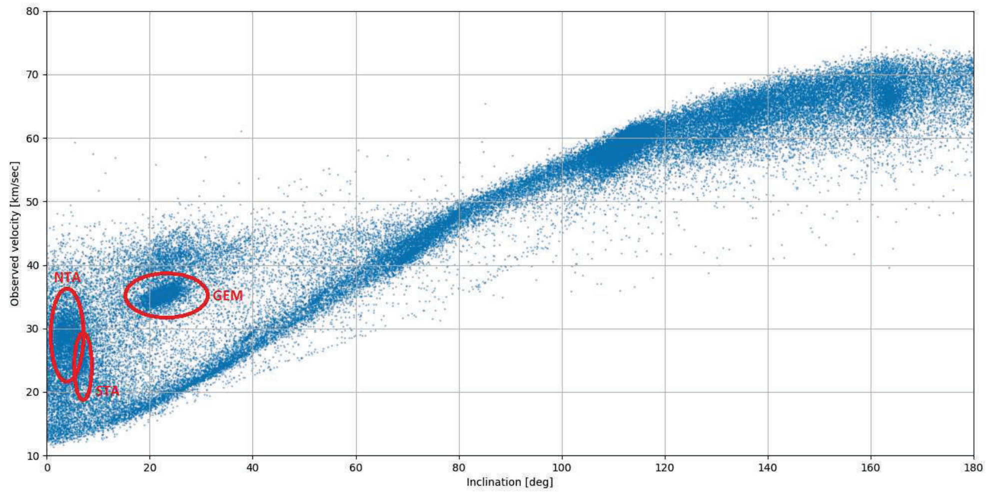

Figure 16 – Three streams with orbital parameters different from the majority.

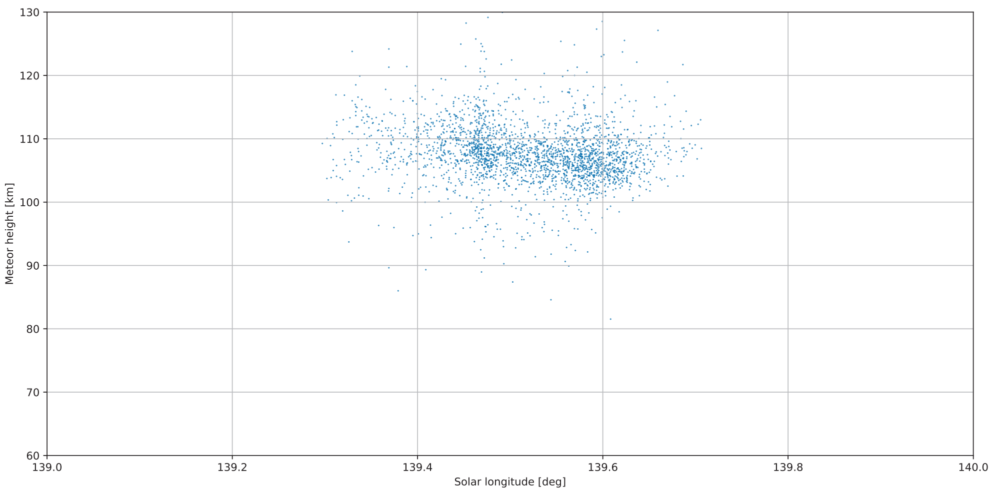

Figure 17 – Perseids start heights during the night of 2016 August 13.

parameters of the swarm but also due to the rotation of the Earth.

If it is true, then over the course of a night, a very rich stream should be affected by this effect, leading to a change in height of the meteors depending on the variation in the distance of the radiant from the apex.

With this in mind, we then choose the Perseids during the night of their peak and analyzed the height of the meteors attributed to this shower.

Figure 16 shows that, as the hours pass, the average height of meteors goes from 110 to 104 km.

9 Comparison with radio data

The kinetic energy of a body depends on its mass and speed.

Higher speeds lead to greater kinetic energy, which leads us to assume that the impact with the first molecules of the ionosphere generates larger cylinders of free ions and electrons.

The intensity of radio signal reflected by the meteors and received on the ground is proportional to the number of free electrons contained in the cylinder of ionized material and this explains why at dawn (at the 6 AM of local time) the intensity of the radio echoes is greater than at 18^{h} (Foschini, 1999).

$$A \propto \frac{1}{l^3} m v^4$$

Where A is the power of the received signal, m is the mass of the meteor and v is its speed, while l represents the distance transmitter/meteor/observer, according with the Proceedings of the IMO radio meteor school 2005 (Belkovich, 2006; Wislez, 2006).

Ignoring the mass role, we can evaluate the influence of the other two quantities.

The variation of the length l of the distance traveled is small: with a height variation of 8 km on a 500 km section, that is the Dijon-Bologna distance, by applying the Pythagorean theorem, a length variation of 4 km is obtained, around 1%.

In contrast, the speed change is much higher, from a minimum of 11 km/s to a maximum of 73 km/s: about 60%.

Hence, the radio signal power is mainly linked to the meteor velocity.

The comparison between the trend of meteoric heights measured via video observations and the inten-

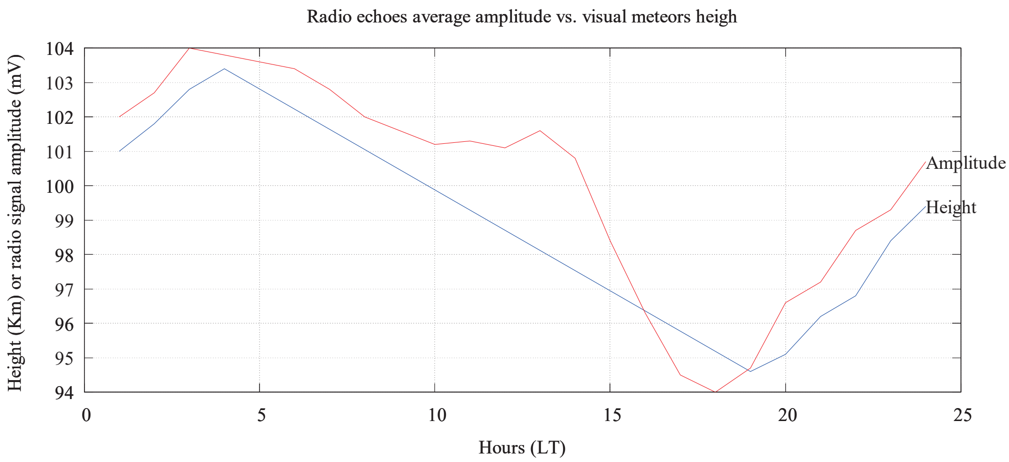

Figure 18 – Comparison of video data and radio data.

sity of the radio signal measured by our amateur radar shows a perfectly similar trend (Figure 18).

10 Conclusions

The meteors light up in the sky at a height on the horizon that varies around the average altitude of about 100 km.

The variation of this height is a function of the kinetic energy of the individual meteoroids.

In this analysis, in which the statistical behavior was evaluated, we ignored the masses of the individual meteoroids, and we examined only the systematic variation of meteor heights and speeds.

The speed variation and the height variation appear to depend directly on parameter i (inclination of the orbit).

The variation (from 0 to 180°) of the inclination i involves an average height variation of about 8 km measurable both during the day and during the year.

This behavior, measured in the visual data of the video footage, appears to be in excellent agreement with the radio data.

References

Belkovich O. I. (2006). "The physics of meteoroid ablation and the formation of ionized meteor trails". In Verbeeck C. and Wislez J.-M., editors, *Proceedings of the Radio Meteor School*. pages 21–26.

Foschini L. (1999). "On the interaction of radio waves with meteoric plasma". *Astronomy and Astrophysics*, **341**, 634–639.

Jenniskens P. (2006). *Meteor Showers and their Parent Comets*. Cambridge University Press.

Verbeeck C. (1997). "Calculating the Sensitivity of a forward Scatter Setup for Underdense Shower Meteors". In Knofel A., editor, *Proceedings of the International Meteor Conference, 15th IMC, Apeldoorn, Netherlands, 1996*. pages 122–132.

Wislez J.-M. (2006). "Meteor astronomy using a forward scatter set-up". In Verbeeck C. and Wislez J.-M., editors, *Proceedings of the Radio Meteor School*. pages 84–106.

Handling Editor: Jean-Louis Rault